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THE WIND FACTOR IN FLIGHT: AN ANALYSIS OF ONE YEAR'S RECORD OF THE AIR MAIL.[1]

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[Washington, D. C., Apr. 27, 1923.]

SYNOPSIS.

From an analysis of one year's records of the Air Mail Service between New York and San Francisco it has been found that at the average altitude of flight, about 1,500 feet above the ground, allowance must be made for a wind of 7 miles per hour from the west. In other words westward flights will, on the average, be made at a speed of 14 miles per hour less than will eastward flights. A more detailed study of the New York to Chicago part of the route gives almost exactly the same wind factor as for the entire transcontinental route. This value of the wind factor has been verified by an examination of 9,267 free-air observations with kites and pilot balloons, and the agreement is remarkably close. The importance of this agreement lies in the fact that, in fixing flight schedules in other regions or at other altitudes, dependence can be placed upon *either* method in case only one is available.

From a further study of the data, schedules that can be guaranteed 90 per cent of the time have been determined for aircraft of any cruising speed between 50 and 150 miles per hour. In making up these schedules allowance has been made for head winds of 36 miles per hour or more in westward flight and 20 miles per hour or more in eastward flight, these being the wind speeds that are shown by kite and balloon records to occur 5 per cent of the time. When they do occur, the flights will be somewhat delayed, but nevertheless completed. During the remaining 5 per cent of the time flights are likely to fail altogether or be seriously delayed because of exceptionally unfavorable weather, such as severe rain or snow storms, poor visibility, etc.

Finally, a general wind curve has been prepared by means of which various schedules based on other percentage performances, greater or less than 90 per cent and for different lengths of routes, may be determined. With the normal and high cruising speeds known quantities, allowance is made for an adverse wind such that the flight can be made in any desired time. The percentage frequency of this adverse wind is then read from the curve and thus is determined the percentage of the time that the desired schedule can be guaranteed.

INTRODUCTION.

The Air Mail Service needs no advertising. Its record speaks for itself. Nevertheless, a brief statement, by way of introduction to this paper, is of interest and there follow, therefore, a few excerpts from "Postal Accomplishments of this Administration," recently distributed in mimeographed form by the National Advisory Committee for Aeronautics:

The Air Mail Service is limited by law to one transcontinental route from New York to San Francisco. This route is 2,680 miles in length, making a round trip of 5,360 miles. This round trip is covered each day, except Sundays and holidays. This necessitates an annual flying schedule of approximately 1,800,000 miles.

The Air Mail Service at present consists of a relay advance of mail from New York across the continent, and vice versa. That is to say, no particular mail is taken for a complete trip across the continent. Certain mail which misses the late night trains out of New York is advanced into Cleveland. Other mail which ordinarily would go into Chicago on a train too late for delivery in the afternoon, is taken from Cleveland into Chicago. This process is repeated in relays across the continent, with the net result that approximately 12,000 pounds of first-class letter mail is advanced each day, a matter of some 3 or 4 hours. It should be noted that this 3 or 4 hour advance may in certain instances mean a real advance of 15 to 18 hours, inasmuch as it may mean the delivery of the mail to consignee late in the evening, which might not otherwise have been delivered until the following morning. * * *

From July 16, 1921, until September 7, 1922, Air-Mail pilots flew approximately 2,000,000 miles without a fatal accident. During the fiscal year ending June 30, 1922, an efficiency of 94.39 was maintained. This means that out of every 100 trips scheduled, 94.39 were finished on schedule time. Our records show that two-thirds of the trips were made in clear weather; one-third were made in foggy, cloudy or stormy weather.

September 16 marked the completion of 10 consecutive weeks of flying the entire transcontinental route with 100 per cent efficiency; that is to say, during these weeks each of the scheduled trips was started and finished exactly on schedule time. The daily route includes the crossing of three mountain ranges, the Alleghenies, the Rockies and the Sierras. * * *

The position of the Post Office Department in the matter of the Air Mail Service is that such information as it is able to develop and such experiments as it is able to follow through to a conclusion are for the benefit of the country at large, and if in this work it is possible to add impetus to the prompt advancement of aeronautics, a notable achievement will have been accomplished for the good of the Nation.

Other parts of this report discuss briefly the types of planes and motors used and plans for undertaking night flying, with a view to maintaining continuous schedule and cutting down the time of the entire trip to about 30 hours. In the present paper we are dealing, not with plans, but with accomplishments, and it can be said, without any exaggeration, that the accomplishments of the Air Mail constitute one of the outstanding developments of the past 2 or 3 years and prove conclusively the practicability of commercial aviation and the wisdom of promoting it with all possible energy and speed. Happily, complete records of flight performance have been kept and there is thus available a large amount of information for use in discussing intelligently the various factors that must be considered in laying out routes, determining schedules, figuring costs, etc. Admittedly, the wind is one of the most important of these factors, and all available data should be used in evaluating it. Such is the purpose of this paper. The records of the Air Mail Service have been used and there have been included some of the results of free-air investigations by means of kites and balloons.

THE FLIGHTS: THEIR NUMBER AND DISTRIBUTION.

The Air Mail records used in this study are those for the period June 1, 1921, to May 31, 1922, inclusive. These give the actual flying time for the 8 sections into which the entire route has been divided. These sections and

[1] Paper presented at Washington, D. C., before the American Meteorological Society on April 16, 1923, and the American Geophysical Union, Section (c) Meteorology, on April 18, 1923.

their lengths in miles are shown in Figure 1 and are as follows:

	Miles.
New York to Cleveland	435
Cleveland to Chicago	335
Chicago to Omaha	425
Omaha to Cheyenne	460
Cheyenne to Rock Springs	240
Rock Springs to Salt Lake	155
Salt Lake to Reno	440
Reno to San Francisco	190
Total	2,680

As stated in the brief report of the Air Mail Service' quoted in part at the beginning of this paper, no flights were attempted on Sundays or holidays. There are thus to be considered 306 instead of 365 days. The actual number of days on which flights were completed along the various sections of the route is given in Table 1, which also contains the average number and the percentage of possible for the entire course. In this and following tables the months are given in regular calendar order, but it is to be understood that January to May refer to 1922, and June to December refer to 1921.

TABLE 1.—*Flights made by Air Mail Service along different sections of the transcontinental route during the period June, 1921, to May, 1922, inclusive.*

Sections.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Annual.
	Number of days available, excluding Sundays and holidays.												
	25	23	27	25	26	26	25	27	25	26	25	26	306
	Number of flights—Westbound.												
New York-Cleveland	20	18	22	23	25	26	25	25	24	24	16	23	271
Cleveland-Chicago	22	22	24	23	26	26	25	27	25	26	20	24	290
Chicago-Omaha	24	21	26	25	25	25	25	27	23	26	17	23	287
Omaha-Cheyenne	24	21	26	22	24	25	23	25	25	25	23	21	284
Cheyenne-Rock Springs	21	17	26	23	25	25	24	25	21	25	22	19	273
Rock Springs-Salt Lake	21	18	25	25	24	25	25	27	24	25	20	21	280
Salt Lake-Reno	17	17	24	23	26	26	25	23	21	26	23	21	272
Reno-San Francisco	15	6	20	21	24	22	25	21	22	25	18	16	235
Average	20.5	17.5	24.1	23.1	24.9	25.0	24.6	25.0	23.1	25.2	19.9	21.0	274
Percentage of possible	82.0	76.1	89.4	92.5	95.7	96.2	98.5	92.6	92.5	97.1	79.5	80.8	89.5
	Number of flights—Eastbound.												
San Francisco-Reno	17	8	18	20	24	25	24	23	22	24	17	17	239
Reno-Salt Lake	18	16	22	23	26	26	24	21	22	26	23	20	267
Salt Lake-Rock Springs	20	18	25	25	24	24	24	27	25	25	23	22	282
Rock Springs-Cheyenne	21	22	27	22	25	24	25	27	25	26	23	23	290
Cheyenne-Omaha	22	22	24	22	26	25	25	27	24	25	24	24	290
Omaha-Chicago	23	22	26	24	26	26	24	24	25	26	19	22	287
Chicago-Cleveland	23	23	25	23	26	26	25	27	25	26	18	23	290
Cleveland-New York	19	20	22	22	25	26	25	25	24	25	16	24	273
Average	20.4	18.9	23.6	22.6	25.2	25.2	24.5	25.1	24.0	25.4	20.4	21.9	277
Percentage of possible	81.5	82.1	87.5	90.5	97.1	97.1	98.0	93.0	96.0	97.6	81.5	84.1	90.6
Average, both ways	20.4	18.2	23.9	22.9	25.1	25.1	24.6	25.1	23.6	25.3	20.1	21.4	276
Percentage of possible	81.8	79.1	88.4	91.5	96.4	96.6	98.2	92.8	94.2	97.4	80.5	82.5	90.1

An examination of the figures in this table brings out quite strikingly the following points:

(1) The number of flights each way, east and west, is approximately the same. Not only is this true for the different sections, but also for the individual months. There were a few exceptions but in general a failure to make a flight in any particular section applied to both directions on the same day. In other words, conditions that were unfavorable for flying were *altogether* unfavorable for it, regardless of direction. Among such conditions we may include rain and snowstorms, deep snow on the ground, fog, thunderstorms and excessively high winds. The last item, high winds, appears to have less importance than the others, so far as complete interruption of flight is concerned. Head winds do of course affect schedule performance—a phase of the subject that will be discussed later—but, unless their speed approaches closely, or exceeds, half that of the aircraft itself, they result only in delay, not in cancellation.

(2) In the present stage of development the summer half of the year is markedly superior to the winter half. From April to October the percentage of possible flights made is generally above 90, the average being about 95; in March it is only slightly less than 90; but from November to February it falls very nearly to 80. Here again we see the influence of unfavorable weather, such as fogs, rain or snow, poor visibility, etc., or bad condition of landing fields, due to rain or snow. Experience and improvement in facilities will at least partially overcome these conditions, but at present they constitute a real handicap for which proper allowance must be made.

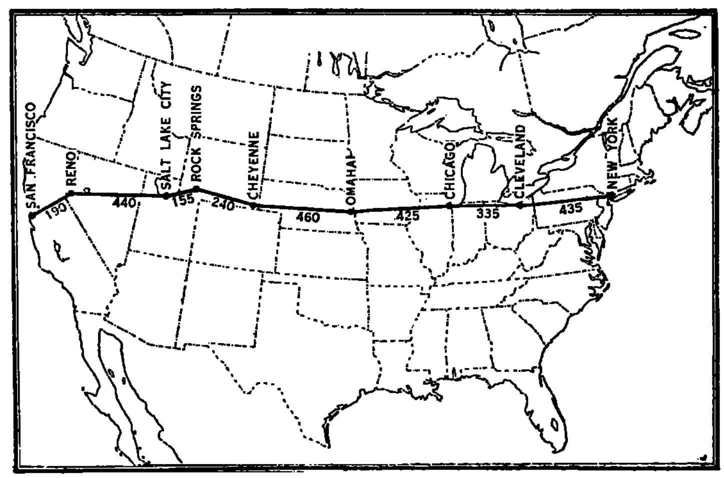

FIG. 1. Air Mail route between New York and San Francisco.

(3) For the year as a whole, there is little difference among the various sections of the route, with the one exception of that between Reno and San Francisco. Presumably this marked exception is due to other influences than that of weather, possibly topography, and little attention need therefore be given it here. Considering the other sections, we find particularly satisfactory the portion of the route between Cleveland and Salt Lake where more than 90 per cent of the scheduled trips were made; the percentage between New York and Cleveland and between Salt Lake and Reno is very close to 90. For the entire route the value is just above 90; if the section between Reno and San Francisco is disregarded, this value is about 92.

THE FLIGHTS: THEIR AVERAGE SPEED.

The records furnished by the Air Mail Service give the actual time in which each flight was made. The data have been tabulated by months for each section of the course, averages have been determined and these averages have been converted into speeds in miles per hour, thus reducing all values to a uniform basis, independent of the length of the various sections. The number of flights used is slightly less than shown in Table 1, since it has been deemed wise to consider only those cases in which flights were made in both directions. The primary purpose of this study is to determine the wind factor as closely as possible, and this purpose would be defeated to some extent if days were included in which a flight was made in one direction and not in the other. However, this procedure resulted in a very small difference, amounting only to an average of 8 flights for each section for the entire year, and to 3 for the New York to Chicago portion of the course. The average speeds are given in Table 2, which also contains separate means for the comparatively level part of the course, New York to Cheyenne, and for the mountainous part, Cheyenne to San Francisco, and finally for all sections combined.

Table 2.—*Average speed, m. p. h., along Air Mail route.*

Sections.	January.	February.	March.	April.	May.	June.	July.	August.	September.
	Westbound.								
New York-Cleveland	89.5	84.8	90.4	87.3	95.8	88.2	84.5	87.0	86.1
Cleveland-Chicago	88.2	85.7	89.6	87.0	90.1	88.6	84.4	84.6	84.2
Chicago-Omaha	86.6	86.2	93.2	95.5	90.0	87.8	82.0	81.6	82.7
Omaha-Cheyenne	84.2	87.5	91.3	94.1	89.3	88.6	88.0	87.0	86.3
Cheyenne-Rock Springs	72.3	70.4	76.7	77.4	78.7	81.4	82.2	76.9	69.8
Rock Springs-Salt Lake	79.1	68.6	77.9	85.6	86.6	75.6	77.5	81.1	78.7
Salt Lake-Reno	94.2	91.9	92.4	95.2	94.8	87.3	92.4	93.2	88.9
Reno-San Francisco	100.5	100.0	90.9	96.4	97.4	82.6	85.6	84.1	88.0
New York-Cheyenne	87.0	86.1	91.2	91.1	91.3	88.3	84.7	85.0	84.9
Cheyenne-San Francisco	86.6	82.9	85.6	89.1	89.7	83.1	86.1	85.3	81.9
New York-San Francisco	86.8	84.8	89.0	90.3	90.7	86.2	85.3	85.2	83.7
	Eastbound.								
San Francisco-Reno	93.1	91.3	106.1	102.7	97.4	88.4	90.9	94.5	99.0
Reno-Salt Lake	100.7	102.8	105.5	103.8	104.3	99.1	99.8	103.5	105.3
Salt Lake-Rock Springs	102.6	98.7	103.3	96.3	96.3	88.6	89.1	95.1	105.4
Rock Springs-Cheyenne	115.4	115.4	106.2	102.1	107.1	89.2	92.3	103.4	108.1
Cheyenne-Omaha	106.2	106.2	99.6	97.7	102.4	87.8	88.5	90.7	92.9
Omaha-Chicago	102.2	104.9	94.2	93.8	94.0	89.3	92.2	94.4	100.5
Chicago-Cleveland	104.7	102.4	93.8	104.0	94.1	88.6	92.3	92.8	97.4
Cleveland-New York	108.8	112.4	105.6	105.3	101.2	95.0	89.9	95.4	101.4
San Francisco-Cheyenne	102.5	102.4	105.5	102.0	102.3	92.9	94.6	100.4	104.7
Cheyenne-New York	105.5	106.6	98.4	99.3	98.1	90.1	90.5	93.3	97.9
San Francisco-New York	104.3	105.0	101.0	100.6	99.7	91.2	92.0	95.9	100.4

Sections.	October.	November.	December.	Spring.	Summer.	Autumn.	Winter.	Annual.
	Westbound.							
New York-Cleveland	85.1	84.1	89.5	91.2	86.6	85.1	87.9	87.7
Cleveland-Chicago	82.3	87.7	84.2	88.9	85.9	84.7	86.0	86.4
Chicago-Omaha	81.6	87.4	85.3	92.9	83.8	83.9	86.0	86.7
Omaha-Cheyenne	85.2	86.3	83.8	91.6	87.9	85.9	85.2	87.6
Cheyenne-Rock Springs	72.9	62.3	69.8	77.6	80.2	68.3	70.8	74.2
Rock Springs-Salt Lake	85.6	76.0	77.5	83.4	78.1	80.1	75.1	79.2
Salt Lake-Reno	90.5	88.0	88.4	94.1	91.0	89.1	91.5	91.4
Reno-San Francisco	88.0	86.4	93.1	94.9	84.1	87.5	97.9	91.1
New York-Cheyenne	83.6	85.3	85.7	91.2	86.0	84.9	86.3	87.1
Cheyenne-San Francisco	84.6	78.3	82.3	88.1	84.8	81.6	83.9	84.6
New York-San Francisco	84.0	83.0	84.4	90.0	85.6	83.6	85.3	86.1
	Eastbound.							
San Francisco-Reno	95.0	99.0	96.0	102.1	91.3	97.7	93.5	96.1
Reno-Salt Lake	99.1	107.8	99.8	104.5	100.8	104.1	101.1	102.6
Salt Lake-Rock Springs	105.4	103.3	97.5	98.6	90.9	104.7	99.6	98.5
Rock Springs-Cheyenne	104.3	117.6	113.7	105.1	95.0	110.0	114.8	106.2
Cheyenne-Omaha	100.4	102.9	106.0	99.9	89.0	98.7	106.1	98.4
Omaha-Chicago	98.4	96.8	101.4	94.0	92.0	98.6	102.8	96.8
Chicago-Cleveland	103.7	102.1	101.2	97.3	91.2	101.1	102.8	98.1
Cleveland-New York	103.8	97.5	109.0	104.0	93.4	100.9	110.1	102.1
San Francisco-Cheyenne	100.4	107.4	101.6	103.3	96.0	104.2	102.2	101.4
Cheyenne-New York	101.4	99.7	104.6	98.8	91.3	99.7	105.6	98.8
San Francisco-New York	101.0	102.5	103.4	100.4	93.0	101.3	104.2	99.8

Deferring for the present a detailed discussion of the figures in this table, we note that the average annual speed over all sections was 86 miles per hour for the westward trip and 100 for the eastward trip. These values indicate that the normal cruising speed of the planes was 93 m. p. h. and that the wind factor amounted to about 7 m. p. h. As a check on this latter value it is possible to use the results of free-air investigations that have been conducted with kites and pilot balloons. Let us first, however, discuss briefly the term "cruising speed" and determine, so far as possible, the altitude at which the flights were made. Unfortunately, these are subject to more or less uncertainty, as the following considerations will show:

1. Cruising speed:
   - (*a*) With a high "head" wind pilots open the motor throttle, the result being a higher than normal airspeed.
   - (*b*) Conversely, with a "tail" wind pilots ease up on the motor, and there results a lower than normal airspeed.
   - (*c*) The effect of (*a*) and (*b*) is to give an apparent wind somewhat less than the actual wind in both cases.
2. Altitude:
   - (*a*) In cold weather and against head winds; also, when there are low clouds or fog, pilots fly as low as possible, anywhere between 100 and 1,500 feet, probably less than 1,000 feet as a rule.
   - (*b*) In warm weather, with good visibility, and especially if there is a tail wind, the flying is done at a much higher altitude, probably between 1,000 and 3,000 feet, sometimes higher still.
   - (*c*) As a working basis we can assume 1,500 feet as the altitude of flight, a value which is believed to be not far from the average.

With both cruising speed and altitude unknown variables we can not fix accurately the actual wind. Nevertheless, it is to be noted that (*a*) and (*b*) under (1), and (*a*) and (*b*) under (2) are to some extent compensatory. That is to say, whereas flights in head winds are at a lower altitude than the average of 1,500 feet and therefore yield apparent winds of less speed than the actual wind at that level, yet on the other hand flights in tail winds are made at a higher altitude than the average with the result that the apparent wind speed is greater than the actual. Again, it should be borne in mind that many of the flights both east and west are made in easterly winds and that the statements in (1*a*) and (1*b*) apply to these as well as to westerly winds. Finally, in many cases no doubt, the motors failed to develop full power, even against high winds. It is thus seen that some of the elements of uncertainty offset one another, at least to a considerable extent. Assuming then that the average altitude of flight was 1,500 feet, that the average wind speed was 7 m. h. p., and that the normal cruising speed was 93 m. p. h., we shall now examine the results of free-air wind observations to provide, if possible, a check on these values.

COMPARISON WITH FREE-AIR WIND OBSERVATIONS.

The data used in this comparison are those that have been obtained by means of kites and pilot balloons. By way of preface it may be remarked that neither method is entirely satisfactory. Balloons can be used only in clear weather, or at any rate only in the clear space beneath cloud layers; they can not be used when rain or snow is falling; since they travel with the wind, they quickly disappear in a horizontal direction when winds are exceptionally strong. Kites, on the other hand, will not fly in very light winds, but are the means of procuring good records in cloudy weather and in fairly strong winds. The two methods thus supplement each other tolerably well, though not perfectly since neither is practicable during rain or snow. However, it is probable that an average of the results provides a close approximation to the true value, and this course has been pursued.

Unfortunately, free-air observations have not been made along all portions of the course, but the eastern part of the country has been fairly well covered. The records chosen for the present study were obtained by means of kites at Drexel, Nebr., and Royal Center, Ind.; and by means of pilot balloons at 2 groups of stations, hereinafter to be referred to as Group 1 and Group 2, the first one comprising Burlington, Vt., Ithaca, N. Y., Lansing, Mich., and Madison, Wis.; and the second, McCook Field, Ohio, Park Field, Tenn., Royal Center, Ind., West Point, Ky., and Wright Field, Ohio.[3] All of these stations are fairly close to the Air Mail route. The individual observations have been added vectorially and the results are presented in Table 3.

TABLE 3.—*Resultant winds, m. p. h. at 1,500 feet above surface.*

Stations.	Method of observation.	Number of observations.	Resultant winds.
Drexel, Nebr.	Kites	1,891	S. 65° W. 4.9.
Royal Center, Ind.	do	607	S. 60° W. 10.3.
Group 1	Balloons	3,874	S. 88° W. 8.7.
Group 2	do	2,895	S. 68° W. 7.8.

The rather large difference between the resultant wind at Drexel and that at the other stations appears to be due to the greater frequency of winds from directions between south and west at the latter. At Drexel winds are about equally frequent from the northwest and southwest quadrants. The values in Table 3 have been resolved into south and west components, and the mean resultant wind is found to be S 70° W 7.7. The average bearing of the course from New York to San Francisco is S 86° W. The difference between this and the resultant wind, S 70° W, viz. 16°, is the angle to be considered in determining wind effect. In order to keep on its course, the airplane must necessarily make a small angle with that course to offset the wind when the latter is neither a straight head wind nor a straight tail wind. This angle will depend upon the direction of the wind and upon its speed relative to that of the plane. It is easily determined from the equation,

$$\sin \beta = \frac{S_w}{S_a} \sin \alpha, \qquad (1)$$

in which β = the angle between the plane and the course;
α = the angle between the wind and the course;
S_a = cruising speed of the airplane;
and S_w = the speed of the wind.

In the present case $\sin \beta = \frac{7.7}{93} \sin 16° = .0228.$

$$\beta = 1°$$

[3] The length of the record varies somewhat for the different stations, but on the average is about 3 years.

The resultant, or ground, speed, S_r, of the airplane will then be

$$\begin{aligned} S_r &= S_a \cos \beta \pm S_w \cos \alpha \qquad (2) \\ &= 93 \cos 1° \pm 7.7 \cos 16° \\ &= 93 \pm 7.4 \\ &= 100.4 \text{ or } 85.6 \end{aligned}$$

These results agree very satisfactorily with the values determined from the actual record of flights, viz., 99.8 and 86.1, respectively, and indicate that we are entirely justified in accepting 7 miles per hour as the effective wind factor in the Air Mail flights. They indicate further that the average effect on any flight schedule may be closely predicted from the resultant wind and the normal cruising speed, even though the cruising speed and altitude are to some extent varied. If these are known more definitely, then the resultant winds determine still more precisely what allowance should be made, a matter of considerable significance in commercial aviation enterprises and one emphasing the importance of extending free-air investigations to all parts of the country as speedily as possible.

VARIATIONS FROM THE AVERAGE.

A knowledge of average performance is important, but it is not sufficient for the purposes of commercial aviation. It is essential also to know the percentage of flights that are delayed and to fix schedules for which the percentage of delays will not exceed certain limiting values. For example, if a contractor wishes to guarantee arrival within schedule limits 95 per cent of the time, he must know the speed of which his planes are capable and he must know the wind velocity which at the selected flying level, is not exceeded more than 5 per cent of the time. With these data, and such allowance for service stops, etc., as is necessary, he can determine a working flight schedule. We shall now examine in greater detail the Air Mail records and the kite and balloon data, with a view to determining what percentage of trips are likely to be delayed with various time schedules; special attention will then be given to that portion of the route between New York and Chicago; and finally the results of the study will be applied to aircraft of various speeds between 50 and 150 m. p. h.

The normal cruising speed of an airplane probably averages from 80 to 90 per cent of its maximum speed. The latter is rarely used, but it constitutes a valuable reserve in case of high head winds or unexpected delays in starting, etc. In all probability, however, a speed closely approaching this maximum is frequently resorted to. This we shall call the plane's "high cruising speed." We shall also assume that the ratio between this and the normal cruising speed is 1 to 0.85.

Let S = high cruising speed,
0.85S = normal cruising speed,
R = resultant wind, or wind factor,
and S_r = plane's resultant or "ground" speed.

We have already found that, for the Air Mail, 0.85S = 93. Then S = 110, a speed which we assume can be resorted to in case of high head winds. We have found also that R = 7, and S_r, for westward flights, = 86, and for eastward, 100.

DELAYS IN WESTWARD FLIGHTS.

As already stated, $S_r = 86$ for these flights. The following table shows the percentage of flights that were made at a lower speed than this.

TABLE 4.—*Percentage of flights westward at less than 86 m. p. h.*

Sections.	Total.	Delays.	Percentage.
New York-Cleveland	269	114	42
Cleveland-Chicago	287	130	45
Chicago-Omaha	278	128	46
Omaha-Cheyenne	277	113	41
Cheyenne-Rock Springs	267	210	79
Rock Springs-Salt Lake	274	188	69
Salt Lake-Reno	264	47	18
Reno-San Francisco	224	74	33
Total	2,140	1,004	47

An inspection of these figures (see also Table 2 in this connection) shows that there is little variation along the different portions of the course from New York to Cheyenne, the average percentage of delays being about 45, thus agreeing closely with the general average. Over the Rocky Mountain region, however, i. e., from Cheyenne to Salt Lake, the percentage of delays is much higher, about 75, probably due in part to greater difficulty in keeping the course because of low-lying clouds, and in part also to stronger westerly winds, since flying is done at a greater altitude above sea level. West of the Rockies, i. e., from Salt Lake to San Francisco, the percentage of delays is much smaller than over any other parts of the course, amounting to only 25. It is not easy to account for this, but the explanation may be that the winds in this region have a less pronounced west component. This appears to be the case, judging from the pilot-balloon observations that have thus far been made. These are not sufficient in number, however, to justify a positive statement on this point.

A more detailed inspection of the original data, of which Table 4 merely gives a summary, indicates that at all points along the course there is a decided seasonal variation. The percentage of delays by seasons for all sections combined is as follows: Spring, 35; summer, 51; autumn, 55; winter, 48.

At first thought we would expect this variation to manifest itself as a small percentage of delays in summer and a large one in winter, but such is not the case. Instead, the minimum is found in spring, the maximum in autumn, and the summer and winter values are nearly identical. It is certain that the west component in the winds is much greater in winter than in summer; and the only plausible explanation for the unexpected results above given seems to be that, in flying against head winds in winter, pilots open the motor throttle to the "high" instead of the "normal" cruising speed. Moreover, as indicated earlier, pilots fly at a lower altitude in winter than in summer, and this tends to offset the difference in wind effects of the two seasons. In spring, because of the prevalence of cloudy weather, the flying is still done at a low altitude, and thus fewer delays occur than in summer because of the difference in altitude or than in winter because of the decreased wind speeds at about the same altitudes. In autumn the reverse is true in each case, because of the greater altitude followed on account of the relatively clear weather.

DELAYS IN EASTWARD FLIGHT.

In this case $S_r = 93 + 7 = 100$. Table 5 shows the percentage of flights that were made at a lower speed than this.

TABLE 5.—*Percentage of flights eastward at less than 100 m. p. h.*

Sections.	Total.	Delays.	Percentage.
San Francisco-Reno	224	133	59
Reno-Salt Lake	264	94	36
Salt Lake-Rock Springs	274	134	49
Rock Springs-Cheyenne	267	99	37
Cheyenne-Omaha	277	151	55
Omaha-Chicago	278	164	59
Chicago-Cleveland	287	161	56
Cleveland-New York	269	109	41
Total	2,140	1,045	49

The average percentage of delays for all parts of the course is 49, practically the same as for the westward flights, the resultant wind being allowed for in each case.

When examined in detail, the original records show a marked seasonal variation as follows: Spring, 44; summer, 73; autumn, 39; winter, 35.

This variation accords with what one would expect and is easily explained: In summer all winds are prevailingly light and therefore material assistance from westerly winds is not frequently experienced. The occurrence of thunderstorms, moreover, adds to the number of delayed flights; in winter marked assistance from westerly winds is frequently found. Even when easterly winds occur, they are not usually very strong at low altitudes, and are not infrequently overrun by westerly winds. The pilot thus can fly above them and gain speed from the overlying westerlies, or in them and be but little delayed by their comparatively low speeds. An exception is to be noted in the part of the course from San Francisco to Salt Lake, where the percentage of delays in winter is nearly as high as in summer. This seems to confirm the remark made earlier that westerly winds in this region of the country are less vigorous than farther east.

From the foregoing discussion it is evident that the number of flights in each direction made at a higher speed and at a lower speed respectively than the average value of S_r is approximately the same, viz, 50 per cent. From an operation standpoint we are little interested in advances on schedule, but we are *vitally* interested in delays. It is thought worth while therefore to assume certain arbitrary schedules, or in other words adopt certain factors of safety, and from the records determine the percentage of flights that fail to arrive within schedule and the average and maximum delay for these flights.

WESTWARD FLIGHT: FACTOR OF SAFETY, 15 M. P. H. HEAD WIND AT NORMAL CRUISING SPEED, OR 32 M. P. H. AT HIGH CRUISING SPEED.

Under this assumption, $S_r = 93 - 15 = 78$. Table 6 shows the percentage of flights that were made at a slower speed than this.

TABLE 6.—*Percentage of flights westward at less than 78 m. p. h.*

Sections.	Total.	Delays.	Percentage.
New York-Cleveland	269	43	16
Cleveland-Chicago	287	63	22
Chicago-Omaha	278	53	19
Omaha-Cheyenne	277	36	13
Cheyenne-Rock Springs	267	155	58
Rock Springs-Salt Lake	274	115	42
Salt Lake-Reno	264	12	4
Reno-San Francisco	224	23	10
Total	2,140	500	23

From these figures it appears that the schedule could not be kept more than about 75 per cent of the time. As in the previous case, however, where a head wind of 7 m. p. h. was allowed, the delays are most frequent, about 50 per cent, in the Rocky Mountain region. If we consider the course from New York to Cheyenne, the percentage of arrivals on or ahead of schedule becomes 82, with a small seasonal variation from 85 in spring and summer to 79 in autumn and winter. It is evident that this performance would not be satisfactory and should be remedied either by using machines having a higher cruising speed, or by allowing a greater factor of safety.

Table 7 shows the average and maximum delay for the different sections of the course for the schedule on which Table 6 is based.

TABLE 7.—*Average and maximum delay, in minutes, for those flights that failed to arrive within schedule.*

Sections.	Average delay.	Maximum delay.
New York-Cleveland	20	55
Cleveland-Chicago	23	97
Chicago-Omaha	34	121
Omaha-Cheyenne	15	39
Cheyenne-Rock Springs	30	160
Rock Springs-Salt Lake	14	80
Salt Lake-Reno	29	97
Reno-San Francisco	13	37

Considering the New York to Chicago part of the course as a unit, we obtain the following values:

Percentage of delays, 19

Average delay in minutes, 26[3]

Maximum delay in minutes, 101[3]

The first value, 19 per cent, agrees closely with the average of the values shown in Table 6 for the four sections from New York to Cheyenne. From these it might at first thought be assumed that head winds of more than 15 miles per hour are encountered less than 20 per cent of the time. This of course is not true; rather, when stronger winds do occur, the reserve power of the motor, $S-0.85\ S$, or at any rate part of it, is brought into play. If $S=110$, then the schedule based on 78 m. p. h. could be maintained, other conditions being favorable, against all head winds up to $15+(110-93)=32$ m. p. h. But the results show that this schedule was maintained only about 80 per cent of the time, which means either that head winds above 32 m. p. h. prevailed on one day out of five, or that poor visibility, engine trouble and other causes, not at all related to the wind, operated to cut down the value of S considerably below 110. In order to determine what proportion of these delays can be attributed to adverse winds a large number of balloon and kite records have been examined and the results are given in the following paragraphs.

For the present purpose the route is sufficiently close to a west-east line to be considered such. If then a wind is blowing straight from that direction, i. e., west, the plane will be delayed in its flight by exactly the speed of that wind. If, however, the wind is from some other direction with a west component, the delay will be less than the speed of the wind, the amount of the decrease being least with WSW or WNW, and greatest with SSW or NNW winds. By transformation of equation (2) it is easy to compute the speeds of wind from the different directions that will produce a resultant delay of 32 m. p. h. in the plane's progress.[4] These values are as follows:

	M. p. h.
W	32
WNW or WSW, approximately	36
NW or SW, approximately	40
NNW or SSW, approximately	50

The kite and balloon records chosen for the study are the same as those used in the preparation of Table 3. The observations, 9,267 in number, were examined, and those tabulated in which the velocities for the appropriate directions equaled or exceeded the values above listed. The results are shown in Table 8.

TABLE 8.—*Percentage frequency of winds at 1,500 feet altitude with west component equaling or exceeding 32 m. p. h.*

Stations.	Method of observation.	Number of observations.	Number with west component 32 m. p. h. or more.	Percentage
Drexel, Nebr	Kites	1,891	193	10.2
Royal Center, Ind	...do	607	47	7.7
Group 1	Balloons	3,874	183	4.8
Group 2	...do	2,895	193	6.7
Mean				7.4

From the mean value here given it appears that head winds would cause a delay in the schedule about once in every two weeks, or in other words that satisfactory performance could be guaranteed 90 per cent of the time, *so far as wind is concerned.* Part of the 23 per cent delayed trips actually experienced, as shown in Table 6, are therefore attributable to other causes, such as failure of engines to develop full power, flying a roundabout route or at high altitudes because of low clouds, etc.

OTHER SELECTED FACTORS OF SAFETY.

The foregoing method of comparing the delays in flights with kite and balloon data has been applied to other assumed factors of safety. It is hardly necessary to give the results at length in this paper, but the detailed figures are available for any who may be interested in them. A general summary follows:

(*a.*) *Westward flight: Factor of safety, 25 m. p. h. at normal cruising speed, or 42 m. p. h. at high cruising speed.*—$S_r=93-25=68$: The average percentage of delays for this schedule was 6, with highest values between Cheyenne and Salt Lake. From New York to Chicago it was only 3 per cent, the average delay being 18 minutes. This is in good agreement with kite and balloon records, which show that winds with a west component of 42 m. p. h. occur 2 per cent of the time. Evidently then this schedule would be very satisfactory, since delays would be experienced about once in 7 weeks.

(*b.*) *Eastward flight: Factor of safety, 10 m. p. h. at normal cruising speed, or 27 m. p. h. at high cruising speed.*—$S_r=93-10=83$: Smaller factors of safety are used for eastward flight, since head winds, in this case easterly winds, are of less average speed than for westward flight. The average percentage of delays for the entire course was 9, with no great variation in the different sections. From Chicago to New York it was 8 per

[3] There is an apparent discrepancy here between the average and maximum delays for the combined course, New York to Chicago, and the sums of the values given in Table 7, where the two sections, New York to Cleveland and Cleveland to Chicago are considered separately. This is easily explained. In many cases there was a delay in one section, but this was more than made up in the other, with the result that there was no delay whatever in the complete trip. For example, calling the three places A, B, and C, let us assume that on one day flight was made 40 minutes ahead of schedule from A to B and was 30 minutes delayed from B to C: and that the reverse of this occurred on the next day. For the entire trip there was no delay on either day but for each section separately there was one delay of 30 minutes to be included in the results given in Table 7.

[4] It is to be noted that allowance is made in equation (2) for the angle that the airplane must make with the course in order to keep on that course.

cent, with an average delay of 43 minutes. Kite and balloon records show that winds with an east component of 27 m. p. h. occur 2.4 per cent of the time, which means that other factors, previously mentioned, were responsible for some of the delays. Considering wind only, and assuming that S = 110, we can safely conclude that this schedule could be maintained 97 per cent of the time, i. e., delays would occur once in 5 weeks.

(*c*.) *Eastward flight: Factor of safety, 20 m. p. h. at normal cruising speed, or 37 m. p. h. at high cruising speed.*—$S_r = 93 - 20 = 73$: The percentage of delays for each section of the course was 4 or less, the average for the entire course being 2 per cent, and for Chicago to New York 1 per cent. Kite and balloon data indicate that winds with an east component of 37 m. p. h. occur 0.7 per cent of the time, from which it appears not only that the agreement is remarkably close but also that this schedule would be a particularly satisfactory one, with delays occurring about 4 times a year.

FLYING BETWEEN NEW YORK AND CHICAGO.

Thus far we have been considering in more or less general terms the entire Air Mail course from New York to San Francisco. At the present time interest is most keen in that portion of it between New York and Chicago, partly because of the commercial importance of those two cities and of others along the route and partly for the reason that if aviation can be proved to be practicable in this region, characterized as it is by frequent storms, high winds and poor visibility, it will certainly be practicable, so far as weather is concerned, in almost any other part of the country. In what follows, therefore, we shall discuss in somewhat greater detail the wind conditions along this portion of the course, as revealed by the Air Mail records and by kite and balloon data. The length of the course is 770 miles. Only those days have been considered in which flights covered this entire distance in both directions. There were thus excluded 3 days in which flights were made from New York to Chicago but not in the other direction; 6 days in which the performance was the reverse of this; and 12 days in which flights were made over only a part of the course either way, e. g., New York to Cleveland, but not on to Chicago, etc.

The number of flights considered is shown, by months, seasons and the year, in Table 9, which also contains the number of available days, excluding Sundays and holidays; the percentage of days on which flights were made; the average speed attained in each direction; and the highest and lowest speeds.

TABLE 9.—*Miscellaneous statistical data for flights between New York and Chicago.*

	January.	February.	March.	April.	May.	June.	July.	August.	September.
Number of days, excluding Sundays and holidays....	25	23	27	25	26	26	25	27	25
Number of flights each way.	19	17	21	21	25	26	25	25	24
Percentage of possible......	76.0	73.9	77.8	84.0	96.2	100.0	100.0	92.6	96.0
	New York-Chicago.								
Average speed m. p. h......	88.8	86.3	90.3	87.4	93.3	88.4	84.1	85.7	85.6
Highest speed m. p. h......	114.1	110.3	108.0	106.1	111.9	104.1	97.5	99.6	101.3
Lowest speed m. p. h.......	68.7	71.3	74.6	70.8	77.1	73.2	73.5	75.7	65.9
	Chicago-New York.								
Average speed m. p. h......	107.2	107.8	100.0	104.2	98.0	92.1	90.9	94.1	99.4
Highest speed m. p. h......	129.4	129.2	123.4	130.5	115.8	110.2	111.3	111.9	128.3
Lowest speed m. p. h.......	84.6	89.0	77.7	76.6	78.8	75.1	64.3	75.3	79.1

TABLE 9.—*Miscellaneous statistical data for flights between New York and Chicago*—Continued.

	October.	November.	December.	Spring.	Summer.	Autumn.	Winter.	Annual.
Number of days, excluding Sundays and holidays...	26	25	26	78	78	76	74	306
Number of flights each way	24	14	20	67	76	62	56	261
Percentage of possible.....	92.3	56.0	76.9	85.9	97.4	81.6	75.7	85.3
	New York-Chicago.							
Average speed m. p. h.....	84.2	85.8	87.0	90.3	86.0	85.2	87.4	87.2
Highest speed m. p. h.....	119.0	109.5	104.5	111.9	104.1	119.0	114.1	119.0
Lowest speed m. p. h......	68.1	74.0	71.0	70.8	73.2	65.9	68.7	65.9
	Chicago-New York.							
Average speed m. p. h.....	104.1	100.4	105.5	100.7	92.3	101.3	106.8	100.3
Highest speed m. p. h.....	136.3	129.8	124.8	130.5	111.9	136.3	129.4	136.3
Lowest speed m. p. h......	79.4	82.2	91.3	76.6	64.3	79.1	84.6	64.3

From the values given in the third line of this table it is apparent that one year's record is not sufficient for the determination of monthly averages; a longer record would smooth out some of the abrupt irregularities. For example, the value for November is much lower than it would be as a rule, and for that matter considerably lower than the general average for the entire route between New York and San Francisco, as may be seen by a glance at Table 1. The large difference between this November value and those for other months, appears to be due to the unusual amount of storminess in the eastern States, resulting from marked cyclonic activity. During the month there was more than double the normal number of cyclones, i. e., low pressure areas, and these produced much cloudiness, accompanied by snow and rain. In spite of this evidently abnormal month, as well as some lesser irregularities in the values given in the table, the latter do bring out, in no uncertain fashion, the marked superiority of the summer over the winter half of the year. From May to October, inclusive, more than 95 per cent of the scheduled flights were made, but the average for the remaining 6 months drops down to about 75 per cent. It is noteworthy that in June and July every flight scheduled was made. Yet these are the months in which most thunderstorms occur in this region. Evidently thunderstorms and local showers do not constitute a serious deterrent to flight. They make necessary a wide detour sometimes and therefore cause delays, but they rarely prevent altogether the completion of a flight. The widespread occurrence of low clouds, however, accompanied as they usually are by rain or snow and characterized by poor visibility, is at present a very big problem for the elimination of which commercial aviation must marshal all its forces. Rain not only interferes with flight but sometimes produces conditions at landing fields which render the take-off and landing difficult and even dangerous. Snow is likewise an impediment in flight and in addition tends to obliterate markings along the route on which the pilot depends for his guidance. If of considerable depth, it may make the take-off and landing of planes hazardous or in extreme cases quite impossible.

The hopeful aspect of this problem is that in large measure it can be solved; there are no insuperable difficulties. Navigation methods must be improved to enable the pilot to fly above the cloud layers and still keep his course. Even in widespread storms there are occasional lulls. Meteorological service must be so enlarged and improved as to enable pilots, by timely warnings, to take advantage of these lulls. Slight delays may result, but at any rate not complete interruption. Suitable signals, both radio and beacon, must be developed so that pilots may be largely independent of such markings as those upon which reliance is now placed. Landing fields must be so graded, drained, and surfaced that rains will have no deleterious effect upon them, and provision must be made to prevent the accumulation of soft snow. By these and other measures the regularity of flight will certainly be greatly improved. In all probability such improvement will be effected in the near future. At present, however, we are more interested in what has actually been accomplished in spite of handicaps, and it seems pertinent, therefore, to consider briefly the days in which flights were not completed in both directions. There were 45 such days, not including Sundays and holidays. A study of the meteorological conditions on those days indicates that 29 of them were very unfavorable for flight. One occurred in May, 2 in August, 1 each in September and October, and the remaining 24 from November to March, inclusive. In all of these 29 cases there was widespread snow or rain, the former prevailing on 13 days. It can not be denied, however, that several of these days were no more unfavorable than were several others during the year on which flights were completed in both directions, and it seems fair to assume, therefore, that other causes contributed in part at least to some of these failures. These "other causes," which may include accidents to the planes, engine trouble, etc., were almost certainly responsible for failures on the remaining 16 of the 45 "flightless" days, since meteorological conditions were good along most of the route on those days. If we include these 16 days with the annual total of 261 in Table 9, we would have a percentage of possible flights amounting to 90.5. If we further assume that flights could have been made on half of the 29 unfavorable days (and this is an entirely justifiable assumption, based on a comparison of those days with several other worse days on which flights were made) the percentage would be 95.1.[5]

Before leaving this part of the subject it is believed worth while to discuss briefly the year as a whole, so far as weather in the region between New York and Chicago is concerned. Temperature was practically normal in January, August, and November; in other months there was an excess of 2° to 6° F., the average for the year being about 3° F. above normal. There were no large abnormalities in precipitation: May and July were close to normal, March, April, and August to November had a slight excess; and June, and December to February, a small deficiency. In no case was the departure more than 1.5 inches in a month. For the year the total was about 2 inches above normal. When we consider storm movement, however, we find considerably greater activity than in most years, only one month, June, showing less. We have already commented on this feature of the weather in November. For the year as a whole, cyclonic areas were about 60 per cent more frequent than normal. Although there were no more than the usual number of storms of marked severity, the large number of moderate storms necessarily produced more frequent changes in weather and a greater amount of cloudiness than would be experienced in most years. Hence, it can be stated quite definitely that the year under consideration provided a rather more severe test for flying between New York and Chicago than would the normal year, and it seems reasonable to conclude that, so far as weather conditions are concerned, flights could be made in both directions between New York and Chicago more than 95 per cent of the time. This statement does not refer to the maintenance of any particular time schedule—a subject to which we shall now turn our attention.

Average, highest and lowest speeds for the westward and eastward flights and for the months, seasons, and the year as a whole, are shown in the last 6 lines of Table 9. From an operation standpoint it is of value to consider each day's flights in connection with the meteorological conditions, but such detailed discussion is of course out of the question. It has been deemed worth while, however, to consider briefly the extreme cases, and the results of this examination are presented in Table 10.

TABLE 10.—*Meteorological conditions on days when highest and lowest speeds were made.*

Season.	Speed.	Date.	Meteorological conditions.
			Highest speeds westward.
	M. p. h.		
Spring....	111.9	May 27, 1922	Easterly winds and clear weather. High north of Lake Superior.
Summer..	104.1	June 2, 1921	Light easterly winds and clear weather. High over New England; low over Wisconsin.
Autumn..	119.0	Oct. 26, 1921	Easterly winds and clear weather. High over St. Lawrence Valley.
Winter....	114.1	Jan. 27, 1922	Do.
			Lowest speeds westward.
Spring....	70.9	Apr. 20, 1922	Strong westerly winds and cloudy weather. Vigorous low over St. Lawrence Valley.
Summer..	73.2	June 13, 1921	Moderate westerly winds and partly cloudy weather with some thunderstorms. Moderate low over St. Lawrence Valley; moderate high in Southern States.
Autumn..	65.9	Sept. 22, 1921	Strong westerly winds and clear weather. Vigorous low north of Great Lakes, with steep pressure gradient south to north.
Winter....	68.7	Jan. 5, 1922	Strong westerly winds and stormy weather. Vigorous low east of Lake Huron.
			Highest speeds eastward.
Spring....	130.5	Apr. 20, 1922	(See under "Lowest speeds westward.")
Summer..	111.9	Aug. 18, 1921	Strong northwesterly winds and partly cloudy weather. Vigorous low over St. Lawrence Valley.
Autumn..	136.3	Oct. 22, 1921	Strong westerly winds and clear weather. Vigorous low north of Lake Huron, with steep pressure gradient south to north.
Winter....	129.4	Jan. 4, 1922	Strong southwesterly winds and comparatively clear weather. Vigorous low over Manitoba.
			Lowest speeds eastward.
Spring....	76.6	Apr. 17, 1922	Strong southerly winds and stormy weather. Vigorous low over Michigan.
Summer..	64.3	July 6, 1921	Light variable winds and occasional thunderstorms. Typical "flat map."
Autumn..	79.1	Sept. 15, 1921	Light, variable winds and cloudy weather. No pronounced high or low.
Winter....	84.6	Jan. 27, 1922	(See under "Highest speeds westward.")

NOTE.—The terms "high" and "low" refer to centers of high and low pressure, respectively. A high north, or a low south, of the course is accompanied by easterly winds along that course; the reverse position of high or low brings westerly winds. The relation between the location of high and low pressure and the highest and lowest speeds attained in flight is well brought out in the figures and remarks above given.

This table shows a striking similarity in the weather conditions that are responsible for high and low speeds in each direction, viz., strong tail winds with clear weather and strong head winds with stormy weather respectively. Two apparent exceptions are noted, on July 6 and September 15, 1921, under "Lowest speeds eastward." Light variable winds prevailed in each case and the weather was fairly good. It is probable that other

[5] This assumption finds further support in a recent report of the Air Mail Service, wherein it is shown that during the calendar year 1922 an efficiency of 95.5% was maintained.

causes, e. g., engine trouble, etc., contributed to these two delays. The highest speed attained in the year, 136.3 m. p. h., on October 22, 1921, was made under almost ideal conditions—clear weather and pressure lines close together and nearly paralleling the latitude.

Reverting now to Table 9, we find that the seasonal variation in the average speeds maintained is very similar to that for the entire course between New York and San Francisco, as shown in Table 2. This variation has already been discussed (third paragraph, following Table 4) and need not be referred to further here. We shall now take the seasonal values and the annual mean and compare them with resultant winds, as determined by means of observations with kites and balloons. The seasonal and annual means are taken from Table 9. The normal cruising speed and the wind factor are then determined, as already indicated in the discussion following Table 2. Finally the resultant wind for each season has been computed in the same way as has that for the year, using the kite and balloon records referred to in the paragraph preceding Table 3. These records serve the present purpose even better than the more general one, i. e., the entire transcontinental course, since they were obtained at stations all of which are comparatively near the Chicago to New York part of the route. The data above outlined are assembled in Table 11.

TABLE 11.—*Mean seasonal and annual speed of flights, m. p. h. between New York and Chicago; also, comparison between wind factor determined therefrom and resultant wind from aerological observations.*

	Spring.	Summer.	Autumn.	Winter.	Annual.
Average speed:	*M. p. h.*	*M. p. h.*	*M. p. h.*	*M. p. h.*	*M. p. h.*
New York-Chicago	90.3	86.0	85.2	87.4	87.2
Chicago-New York	100.7	92.3	101.3	106.8	100.3
Normal cruising speed	95.5	89.2	93.2	97.1	93.8
Wind factor from data above given	5.2	3.2	8.0	9.7	6.6
Resultant wind from kite and pilot balloon records	5.4	5.6	8.7	10.7	7.4

The annual cruising speed, 93.8 m. p. h., in line 3 of this table is in striking agreement with that found for the entire route between New York and San Francisco, viz., 93.0 m. p. h. This slight difference is of no real significance, but it may be remarked that the higher value for the eastern section of the course is probably due to the exceptionally favorable conditions for westward flight in the month of May, resulting in a higher average speed than was maintained in any other month. (See Table 9.) It seems proper to make some allowance for this, and we shall therefore continue to use 93 m. p. h. as the normal cruising speed. The values in the table show a seasonal variation, but this does not mean that the normal cruising speed itself varies. Rather, in winter the winds from all directions are stronger than in summer. In winds approximately parallel with the course, the assistance in one direction is offset by the resistance in the other, or nearly so; but in many cases cross winds prevail and it then becomes necessary to increase the speed of the airplane in *both* directions, the result being to give a mean speed which is somewhat higher than the annual cruising speed. In summer, the delays are caused to a less extent by winds than by thunderstorms, squalls, etc., which necessitate flying off course. Such delays are experienced in both westward and eastward flight, and result in cutting down the average speed somewhat below the normal cruising speed. The variations are not large, however, amounting to less than 5 m. p. h. in each season. Even the monthly values, though based on a small number of cases, show almost equally satisfactory agreement, as follows:

	Average m. p. h.
January	98.0
February	97.0
March	95.2
April	95.8
May	95.6
June	90.2
July	87.5
August	89.9
September	92.5
October	94.2
November	93.1
December	96.2

The last two lines of Table 11 give a comparison of the wind factor, indicated by mean westward and eastward speeds, and the resultant winds, as observed by means of kites and balloons. Except in summer the agreement is close, the resultant wind being slightly the higher of the two in all seasons. In summer various factors of uncertainty, already referred to, such as thunderstorms, squalls, etc., tend to mask the effects of winds which for the most part are light and variable. It is therefore not surprising to find a fairly large difference in this season. The agreement in the means for the year is excellent, each being close to 7 m. p. h., which is the value already used for the entire transcontinental route.

In Tables 12 and 13 the Air Mail records are presented in such form as to show the number and percentage of flights that were made at or above different average speeds. The figures in the second column of the tables give the equivalent duration of the flights in hours and hundredths.

TABLE 12.—*Number and percentage of flights made from New York to Chicago at or above different average speeds.*

Speed (m. p. h.).	Time of flight.	Number of flights.					Percentage of total number.				
		Spring.	Summer.	Autumn.	Winter.	Annual.	Spring.	Summer.	Autumn.	Winter.	Annual.
	Hrs.										
120	6.42	0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
118	6.53	0	0	1	0	1	0.0	0.0	1.6	0.0	0.4
116	6.64	0	0	1	0	1	0.0	0.0	1.6	0.0	0.4
114	6.75	0	0	1	0	1	0.0	0.0	1.6	0.0	0.4
112	6.88	0	0	1	1	2	0.0	0.0	1.6	1.8	0.8
110	7.00	2	0	1	2	5	3.0	0.0	1.6	3.6	1.9
108	7.13	2	0	2	2	6	3.0	0.0	3.2	3.6	2.3
106	7.26	5	0	2	3	10	7.5	0.0	3.2	5.3	3.8
104	7.40	7	0	3	6	16	10.4	0.0	4.8	10.7	6.1
102	7.55	9	1	3	6	19	13.4	1.3	4.8	10.7	7.3
100	7.70	15	2	6	7	30	22.4	2.6	9.7	12.5	11.5
98	7.86	22	8	9	10	49	32.8	10.5	14.5	17.8	18.8
96	8.02	27	11	10	12	60	40.3	14.5	16.1	21.4	23.0
94	8.19	30	17	10	15	72	44.8	22.4	16.1	26.8	27.6
92	8.37	35	20	17	19	91	52.2	26.3	27.4	33.9	34.9
90	8.56	42	28	21	22	113	62.7	36.8	33.9	39.3	43.3
88	8.75	43	34	26	24	127	64.2	44.7	41.9	42.8	48.6
86	8.95	46	36	30	30	142	68.7	47.4	48.4	53.6	54.4
84	9.17	48	44	33	37	162	71.6	57.9	53.2	66.1	62.1
82	9.39	53	52	40	43	188	79.1	68.4	64.5	76.8	72.0
80	9.62	55	58	47	46	206	82.1	76.3	75.8	82.1	78.9
78	9.87	56	63	50	48	217	83.6	82.9	80.6	85.7	83.1
76	10.13	61	73	55	52	241	91.0	96.0	88.7	92.8	92.3
74	10.41	65	74	56	52	247	97.0	97.4	90.3	92.8	94.6
72	10.69	66	76	57	53	252	98.5	100.0	91.9	94.6	96.5
70	11.00	67	76	59	55	257	100.0	100.0	95.2	98.2	98.5
68	11.32	67	76	61	56	260	100.0	100.0	198.4	100.0	99.6
66	11.67	67	76	62	56	261	100.0	100.0	100.0	100.0	100.0

TABLE 13.—*Number and percentage of flights made from Chicago to New York at or above different average speeds.*

Speed (m. p. h.).	Time of flight.	Spring.	Summer.	Autumn.	Winter.	Annual.	Spring.	Summer.	Autumn.	Winter.	Annual.
		Number of flights.					Percentage of total number.				
	Hrs.										
138	5.58	0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
136	5.66	0	0	1	0	1	0.0	0.0	1.6	0.0	0.4
134	5.75	0	0	1	0	1	0.0	0.0	1.6	0.0	0.4
132	5.83	0	0	1	0	1	0.0	0.0	1.6	0.0	0.4
130	5.92	1	0	1	0	2	1.5	0.0	1.6	0.0	0.8
128	6.02	2	0	4	2	8	3.0	0.0	6.4	3.6	3.1
126	6.11	2	0	4	2	8	3.0	0.0	6.4	3.6	3.1
124	6.21	3	0	4	5	12	4.5	0.0	6.4	8.9	4.6
122	6.31	5	0	6	5	16	7.5	0.0	9.7	8.9	6.1
120	6.42	6	0	6	9	21	8.9	0.0	9.7	16.1	8.0
118	6.53	7	0	7	10	24	10.4	0.0	11.3	17.8	9.2
116	6.64	7	0	12	14	33	10.4	0.0	19.3	25.0	12.6
114	6.75	9	0	14	17	40	13.4	0.0	22.6	30.3	15.3
112	6.88	12	0	16	18	46	17.9	0.0	25.8	32.1	17.6
110	7.00	14	5	17	24	60	20.9	6.6	27.4	42.8	23.0
108	7.13	17	5	20	28	70	25.4	6.6	32.2	50.0	26.8
106	7.26	18	7	22	32	79	26.9	9.2	35.5	57.1	30.3
104	7.40	26	11	25	36	98	38.8	14.5	40.3	64.3	37.5
102	7.55	37	20	27	42	126	55.2	26.3	43.5	75.0	48.3
100	7.70	41	28	35	43	147	61.2	36.8	56.4	76.8	56.3
98	7.86	43	34	38	44	159	64.2	44.7	61.3	78.6	60.9
96	8.02	46	34	44	45	169	68.6	44.7	71.0	80.3	64.7
94	8.19	51	36	47	47	181	76.1	47.4	75.8	83.9	69.3
92	8.37	54	41	49	50	194	80.6	53.9	79.0	89.3	74.3
90	8.56	56	48	54	54	212	83.6	63.1	87.1	96.4	81.2
88	8.75	59	52	55	55	221	88.0	68.4	88.7	98.2	84.7
86	8.95	60	58	55	55	228	89.5	76.3	88.7	98.2	87.3
84	9.17	62	63	58	56	239	92.5	82.9	93.5	100.0	91.6
82	9.39	63	65	59	56	243	94.0	85.5	95.2	100.0	93.1
80	9.62	64	67	60	56	247	95.5	88.1	96.8	100.0	94.6
78	9.87	65	69	62	56	252	97.0	90.8	100.0	100.0	96.5
76	10.13	67	69	62	56	254	100.0	90.8	100.0	100.0	97.3
74	10.41	67	73	62	56	258	100.0	96.0	100.0	100.0	98.8
72	10.69	67	74	62	56	259	100.0	97.4	100.0	100.0	99.2
70	11.00	67	75	62	56	260	100.0	98.7	100.0	100.0	99.6
68	11.32	67	75	62	56	260	100.0	98.7	100.0	100.0	99.6
66	11.67	67	75	62	56	260	100.0	98.7	100.0	100.0	99.6
64	12.03	67	76	62	56	261	100.0	100.0	100.0	100.0	100.0

The figures in the bottom line of columns 3 to 7 inclusive in each table represent the total number of flights made. The percentage of delayed flights for the schedules given in the first two columns may be readily obtained by subtracting from 100 the values in the five columns at the right of each table.

The seasonal variation is well shown by these data. It is of course greatest for the highest speeds since the latter result from strong assisting winds, and these occur most frequently in the winter half of the year. From an operation standpoint, as already stated, we are most interested in speeds that can be maintained a large part of the time and at these lower speeds, 75 to 80 miles per hour, the seasonal variation is small. This being the case, it seems scarcely necessary to determine for each season, the allowance that should be made for head winds, more particularly since in any aviation enterprise involving day to day flight bids must be made and contracts placed on a yearly basis. Considering then only the annual percentages we have plotted these, i. e., the figures in the last columns of Tables 12 and 13, in figures 2 and 3 respectively. Ordinates represent the percentages of flights that were made at or above the speeds indicated by abscissae.

The curve in figure 2 shows that approximately 50 per cent of the flights were made at a speed of 86 m. p. h. or more, which is the normal cruising speed less the resultant wind, $0.85S-R$; and about 30 per cent were made at or above the normal cruising speed, 93 m. p. h. These latter represent flights in which material assistance was realized from easterly winds. The part of the curve to the right of 93 m. p. h. indicates flights whose speed was cut down by westerly winds. In both cases the exact relation of the plane's airspeed to the resulting ground speed must be chosen somewhat arbitrarily, since, as already stated, with tail winds pilots may ease up on the motor, and with head winds the airplane's cruising speed may be increased in proportion to the strength of those winds, until its limit has been reached, viz, $S=110$ m. p. h. Most interest, of course, lies in the upper part of the curve, that showing a high percentage. If arrival on or ahead of schedule 95 per cent of the time is taken as a satisfactory operating performance, inspection of the curve indicates that this would be realized, in the case of the Mail planes, with a schedule based on a speed of 74 m. p. h. This means, if we still assume $S=110$, that 5 per cent of the time there occur head winds exceeding a speed whose value we can readily determine from aerological observations.

The kite and balloon records which have been used in the early part of this paper have been examined for the present purpose also and as a result it is found that at an altitude of 1,500 feet a wind with a west component of 36 m. p. h. or more occurs 5.2 per cent of the time. If this value, 36, were placed at the bottom of the figure under the ground speed of 74, and other wind speeds were properly placed with reference thereto, the zero point would fall under 110, from which it is evident that the latter value represents very closely the high cruising speed of the planes, as originally deduced from the assumption that the normal cruising speed, 93, is 85 per cent of the high cruising speed. It should be distinctly borne in mind that with lower wind speeds the speed of the planes is likewise lowered and that therefore the wind scale does not fit the curve except for high winds which it is necessary to overcome by letting out the motor to its limit. For lower wind speeds the zero of the scale would shift successively to the right, until it reached 93 m. p. h. for no wind. With easterly, i. e., tail winds, the zero would again shift slightly to the right, the amount depending upon the strength of those winds, and the wind scale would increase in reverse direction, i. e., from right to left. With a shifting zero it would be difficult to evaluate the wind effect for the lower speeds and fortunately it is not necessary to do so, since interest is centered almost entirely in a high percentage of schedule maintenance. It is believed worth while, however, to endeavor to justify the assumption of a shifting zero, and for this purpose the kite and balloon records already used in this paper have been examined with a view to determining what percentage have a west component, i. e., are from any direction between N 1° W and S 1° W, regardless of speed. These records give the following results:

	Percentage of winds with west components.
Drexel, Nebr.	65
Royal Center, Ind.	73
Group 1	73
Group 2	68
Mean	70

The remaining 30 per cent include calms and winds with an east component. It has been stated that with no wind the zero of the scale at the bottom of figure 2 would fall under the ground speed of 93. If this be so, then the curve at the abscissa of 93 should have an ordinate of 30. In reality it passes through 31—an agreement which sufficiently justifies the assumption as to the shifting zero.

In confirmation of the statement that with very high winds advantage is taken of the plane's maximum speed of 110 m. p. h. it may be added that kite and balloon records show that winds with a west component of 42 m. p. h. occur 2.0 per cent of the time, whereas the curve in figure 2 indicates 0.4 per cent. Under the conditions specified, therefore, viz., that the normal cruising speed, 93 m. p. h., is 85 per cent of the maximum that can be maintained over the whole course and that allowance is made for winds with a west component of 36 m. p. h. a flight speed of 74 miles per hour or better can be guaranteed 95 per cent of the time.

The curve in figure 3 furnishes information for eastward flight similar to that in figure 2 for westward flight. The significance of the wind effect is well brought out by a comparison of the two figures. Figure 3 indicates that approximately 50 per cent of the flights were made at a higher speed than 100 m. p. h. and that in about 70 per cent the normal cruising speed, 93 m. p. h., was exceeded. The part of the curve to the left of 93 represents flights in which material assistance was experienced from tail, i. e., westerly winds; that to the right, those flights whose speed was cut down by easterly winds. In the upper part of the curve we find that 95 per cent of the flights were made at or above a speed of 80 m. p. h. An examination of kite and balloon records shows that

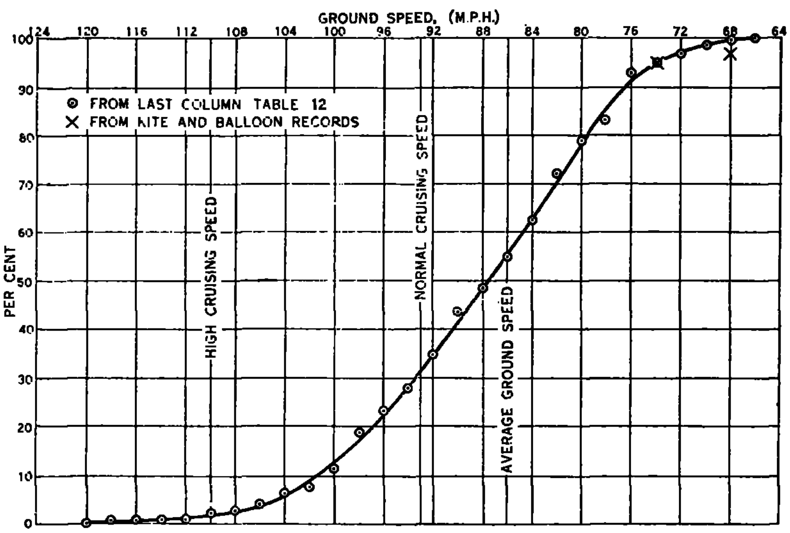

FIG. 2. Percentage of trips made from New York to Chicago, 770 miles, at different average speeds with airplanes whose normal cruising speed is 93 miles per hour.

winds with an east component of 20 m. p. h. or more occur 4.9 per cent of the time. If this value were placed under 80 and the scale extended to its zero, the latter would fall under 100 instead of 110 as in figure 2. This is not surprising; it means simply that in eastward flight it is seldom necessary to bring into play the reserve power of the motor, or at any rate an appreciable part of it. As in figure 2, a second point on the curve has been compared with the kite and balloon records. The latter give 2.4 per cent as the frequency of winds having an east component of 27 m. p. h., and the curve at this point indicates about 1 per cent.

APPLICATION TO AIRCRAFT OF DIFFERENT SPEEDS.

Having determined what may be called the "critical" wind speed for a 95 per cent schedule maintenance, we can now apply the results of this study to aircraft of any speed. At the present time the normal cruising speed of aircraft, including lighter than air, ranges approximately between 50 and 150 m. p. h. Still assuming that this normal cruising speed is 85 per cent of the maximum speed that can be maintained, we can quickly compute the latter and from it deduct the wind for which allowance must be made, viz., 36 m. p. h. for westward, and 20 m. p. h. for eastward flight. This value divided into 770, the length of the course, gives the schedule in hours that can be kept 95 per cent of the time. The results are shown in Table 14 and in figures 4 and 5.

TABLE 14.—*Time schedules for flights between New York and Chicago.*

Normal cruising speed (0.85S).	High cruising speed (S).	Westward flights.		Eastward flights.	
		Allowance for wind (S−36).	Time schedule.	Allowance for wind (S−20).	Time schedule.
			Hours.		*Hours.*
50	59	23	33.48	39	19.74
60	71	35	22.00	51	15.10
70	82	46	16.74	62	12.42
80	94	58	13.28	74	10.41
90	106	70	11.00	86	8.95
93	109	73	10.55	89	8.65
100	118	82	9.39	98	7.86
110	129	93	8.28	109	7.06
120	141	105	7.33	121	6.36
130	153	117	6.58	133	5.79
140	165	129	5.97	145	5.31
150	176	140	5.50	156	4.93

An inspection of the figures brings out very clearly the difficulties of the westward trip for low-speed aircraft. With a normal cruising speed of 50 m. p. h. almost twice as much time would be required as for the eastward trip. The importance of the wind factor diminishes of course with the higher cruising speeds, and with values of the latter above 100 m. p. h. the difference in the two directions is not large, amounting to about 1½ hours at 100 m. p. h. and slightly more than half an hour at 150 m. p. h. In all cases we are assuming that against high head winds the speed of the aircraft can be increased from 0.85S to S.

In the foregoing discussion no allowance has been made for service stops or for change in time. We have considered only the actual time during which the planes were in the air. As stated in the report, quoted in part at the begining of this paper, the Air Mail Service at present consists of a relay advance of mail from New York to Cleveland, Cleveland to Chicago, and so on. In addition, 20-minute service stops are made at Bellefonte, Pa., and at Bryan, Ohio. The length of time required for stops in commercial aviation would vary according to the character of the service rendered. If this were for mail, express or passenger transportation the stops would probably be short, but if for freight they would necessarily be somewhat longer. Probably one stop would be sufficient—that at Cleveland. As a working basis we can assume that it would be one hour. It is to be noted that the relative importance of this, since it is a constant, increases with the higher speed aircraft.

In a commercial sense the wind factor is offset—to a considerable extent for low cruising speeds and completely so for high—by the change in time. For instance, Table 14 shows that the schedule for a normal cruising speed of 90 m. p. h. is 11 hours from New York to Chicago and practically 9 hours in the opposite direction. Including one hour for service stops, these become 12 and 10 hours respectively. By the clock, however, (and this is the important consideration in business) the trip is made in each direction in 11 hours. Thus, mail leaving the Terminal Fields at each city at 8 p. m. arrives at the other on the following morning at 7 a. m. Applying the change in time to the values in columns 4 and 6 of Table 14 and making an allowance of 1 hour for stops, we have the revised schedule given in Table 15 and in figure 6.[6]

[6] Commercial enterprise would have to add to this the time required to reach the Terminal Fields from the center of town, at both terminals, in making comparison with rail schedules.

TABLE 15.—*Time schedules for flights between New York and Chicago Terminal Landing Fields, including 1 hour for stops and allowing for change in time.*

Normal cruising speed.	Time in hours.	
	New York to Chicago.	Chicago to New York.
50	33.48	21.74
60	22.00	17.10
70	16.74	14.42
80	13.28	12.41
90	11.00	10.95
100	9.39	9.86
110	8.28	9.06
120	7.33	8.36
130	6.58	7.79
140	5.97	7.31
150	5.50	6.93

all the days in the year and that 95 per cent of those flights are made in accordance with the schedules shown in figures 4 and 5, we have 90.2 as the final percentage of schedule maintenance throughout the year. It is to be noted in figures 2 and 3 that the amount of delay in those flights, 5 per cent of the total, that would fail to arrive within the schedule, is not large, and it is worthy of remark that other means of transportation, rail, steamship, motor truck, etc., are themselves subject to occasional delays. Finally, if the number of complete failures can be reduced by overcoming the effects of unfavorable weather (again not including the wind factor), the normal percentage of schedule maintenance here shown to be 90.2, will be increased accordingly.

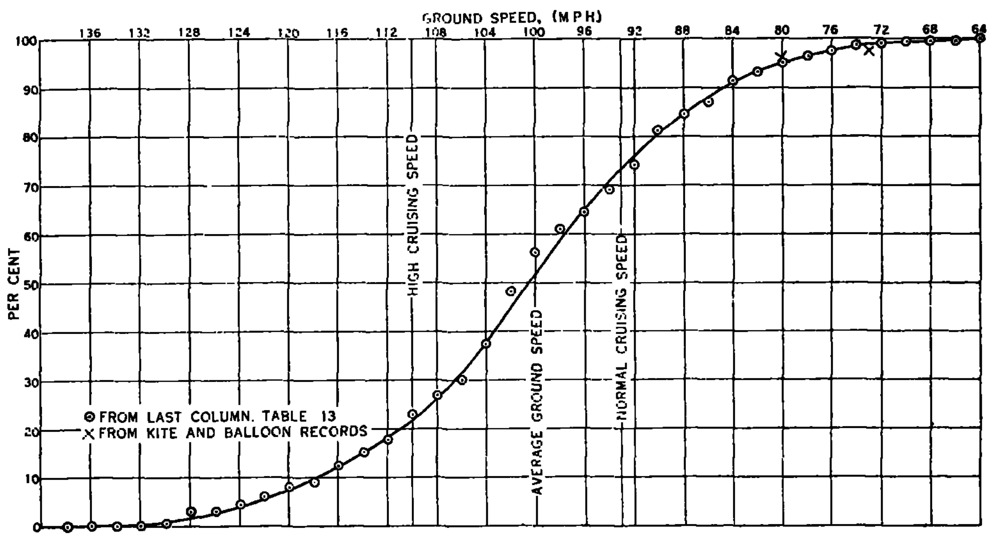

FIG. 3. Percentage of trips made from Chicago to New York, 770 miles, at different average speeds with airplanes whose normal cruising speed is 93 miles per hour.

From the table and curves it is apparent that, with aircraft of high cruising speed, *advantage lies with the westward trip, so far as commercial service is concerned.*

It must be distinctly understood that the data given in figures 2 to 5 and in Tables 14 and 15 have reference solely to those days during the year on which flights were completed in both directions. As shown in Table 9, these days constituted 85.3 per cent of the total. Failures on 14.7 per cent of the days were due to various causes, such as bad weather (not including high winds), motor trouble, necessity for repairs to the plane en route, etc. As has already been indicated some of these causes of failure will become nonexistent with improvement in equipment and in facilities for handling aircraft at landing fields. It has also been shown that the weather was no more unfavorable on some days when failures were recorded than on others when flights were successful. Finally, in a few cases flights were completed in one direction only. If these latter were included, the percentage would become 86.3 for the westward, and 87.2 for the eastward trip. On the basis of the points above briefly reviewed we have previously stated that a conservative estimate would place the unavoidable percentage of failures to complete flights at no more than 5. Assuming, then, that flights are made on 95 per cent of

THE GENERAL WIND CURVE FOR DETERMINING VARIOUS SCHEDULES.

Figures 4 to 6, inclusive, represent the application of the preceding analysis to a particular percentage performance of aircraft over a definite route, that between New York and Chicago. It may be desired to determine schedules based on other performances, greater or less than 90 per cent and for different lengths of routes. For this purpose figure 7 has been prepared to show the number of times during a normal year that east or west winds of varying strength occur. The following example will indicate how this curve may be applied:

An aircraft with a normal cruising speed of 80 m. p. h. and a high cruising speed of 90 m. p. h. is to be operated over a route 1,000 miles in length. It is desired to determine what percentage of the trips will be made in a flying time of 13 hours or less. (To compare with train schedules, the length of time to get from the terminal cities to the terminal airports, time consumed in any stops en route, and the change in clock time going east or west must of course be added to the flying time.) From figure 7 we read that a wind from the west of 13 m. p. h., or more, occurs 30 per cent of the time. Assuming that the aircraft maintains its high cruising speed of 90 m. p. h. over the entire distance, the resultant ground speed will therefore be 77 m. p. h., or less, for 30 per cent of the westbound trips. Dividing the distance traveled, 1,000 miles, by this ground speed the flying time is found to be just 13 hours. Hence it is determined that such an aircraft could maintain a 13-hour schedule 70 per cent of the time. The exact amount of delay due to wind which would be encountered during any proportion of the remaining 30 per cent of the trips may be similarly read from the curve. During 30 per cent of the trips the curve indicates that there would be a favoring wind on west-bound flights. The exact amount which the airspeed of the aircraft can be reduced, and still arrive within 13 hours, can be read from the curve, thereby determining the amount of fuel which may be saved by running the engines throttled. Similar calculations may be made for east-bound flights and for aircraft of different cruising speeds, or for different lengths of routes.

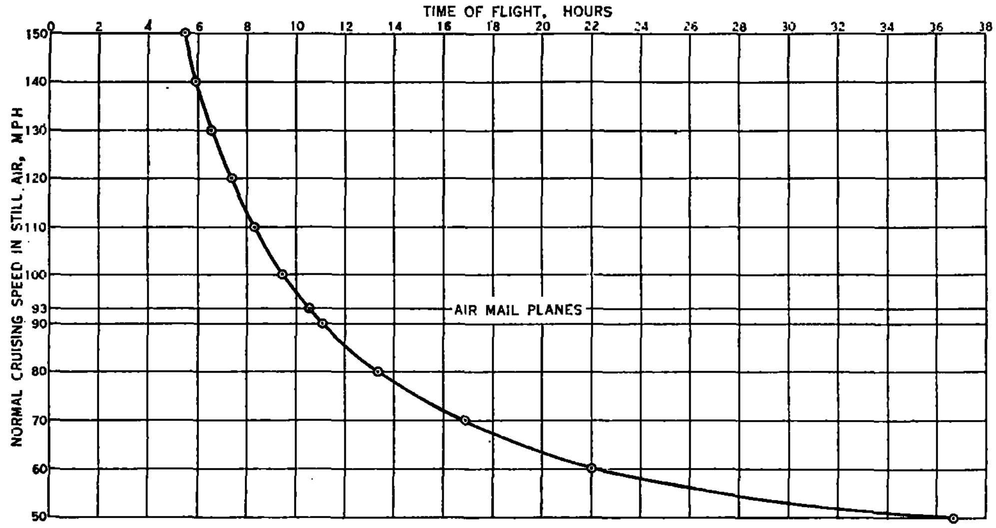

FIG. 4. Curve showing schedules for flight from New York to Chicago, 770 miles, that can be guaranteed 90 per cent of the time for aircraft of different normal cruising speeds. Allowance made for head and cross winds; no allowance made for service stops or change in time.

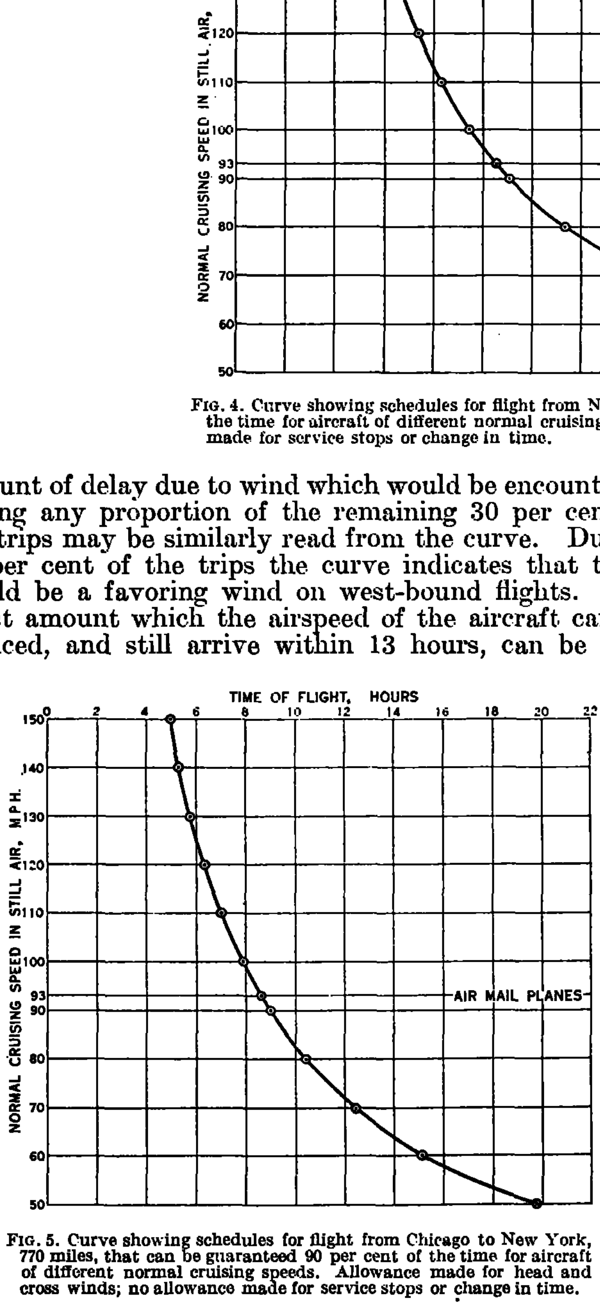

FIG. 5. Curve showing schedules for flight from Chicago to New York, 770 miles, that can be guaranteed 90 per cent of the time for aircraft of different normal cruising speeds. Allowance made for head and cross winds; no allowance made for service stops or change in time.

Figure 7 brings out strikingly several features already referred to in the text, of which three are of particular interest:

(*a*) The percentage of time abnormally strong east or west winds occur, as deduced from (1) kite and balloon records, (2) westbound flights, and (3) eastbound flights, agrees very closely.

(*b*) The percentage of time west winds of moderate strength occur, as deduced from westbound flights, is consistently lower by two or three miles than that deduced from eastbound flights. This is exactly what would be anticipated, as explained in the text following Table 2. The point where the wind curve passes from west to east is especially interesting; kite and balloon records show this to be at 70 per cent (see text following Tables 12 and 13); westbound flights are able to avoid west winds a small fraction of the time by flying at a lower altitude and thus pass from the region of west winds to east at the point 67 per cent (see Figure 2); eastbound flights prolong the region of westbound, favoring winds slightly by flying at a higher altitude and thus pass from west to east winds at 73 per cent (see figure 3).

(*c*) Finally, the percentage of winds determined from kite and balloon records is in almost every instance slightly greater than that deduced from either east or westbound flights. This is exactly what would be expected since the flying records give the resultant effect of the winds occurring along the route during all the hours of the flight, whereas the kite and balloon records show only the winds over a fixed point at the time of observations, not what may be denoted as the "integrated" wind effect.

It should be noted that figures 2 and 3 showing the ground speed of Mail planes on west and east flights, respectively, can not be used directly to give the wind percentages of figure 7 until some assumption is made as to the actual average airspeed maintained by the planes when flying against a strong opposing wind or with a strong favorable wind. This actual airspeed will vary, as already explained, from the highest cruising speed which the plane can maintain, down to a speed somewhat less than the normal cruising speed when flying with an especially favorable wind. The determination of this actual average airspeed, within the limits mentioned, for varying wind conditions must be somewhat empirical, as no record of the actual airspeed is kept by the Air Mail, nor is the airspeed of a plane likely to be maintained constant throughout an entire flight.

The evaluation of this "shifting zero" from the normal cruising airspeed may, however, be made from a knowledge of the practice of pilots when flying a route with favoring or opposing winds. In the present instance a smooth curve has been drawn (not reproduced, however, in the published figures) on figures 2 and 3 paralleling the normal cruising speed line where the winds encountered are only a few miles opposing or favorable, and passing through the point where no winds occur—that is, where the normal cruising speed equals the plane's resultant ground speed. As opposing winds of increasing strength are encountered, the airspeed is increased toward the high cruising speed, 110 m. p. h.; as favorable winds of increasing strength are encountered the average airspeed is assumed to decrease toward a throttled speed of about 85 m. p. h. The exact choice of these airspeeds is not important, as any other reasonable assumption in fair accord with actual practice would not appreciably change the wind values shown in figure 7. The important fact about figure 7 is the remarkable check it presents between westbound and eastbound flights and the results of kite and balloon records.

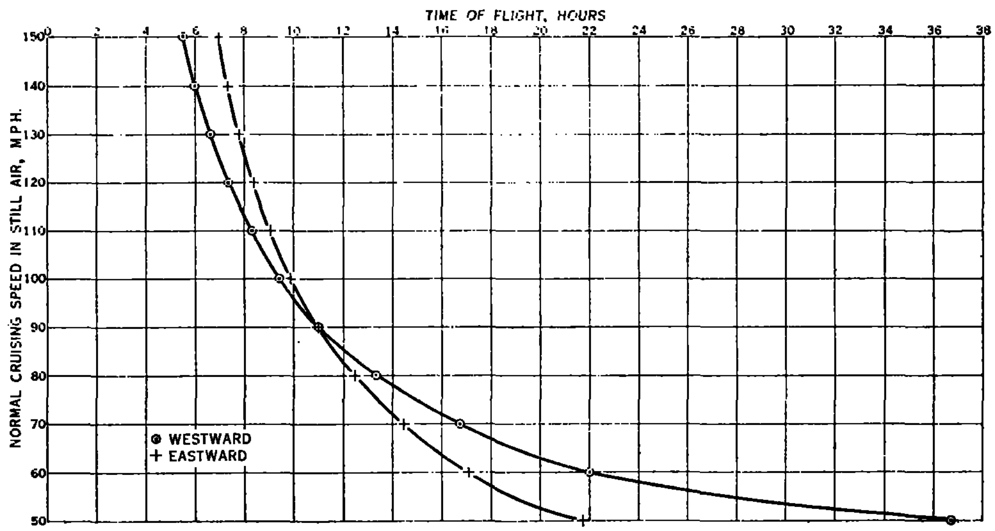

FIG. 6. Curves showing schedules for westward and eastward flight between New York and Chicago, 770 miles, that can be guaranteed 90 per cent of the time for aircraft of different normal cruising speeds. Allowance made for head and cross winds; for 1 hour service stops each way; and for change in time.

SUMMARY AND CONCLUSIONS.

1. From an analysis of the Air Mail records it has been found that the wind factor for the route between New York and San Francisco is approximately 7 miles per hour from the west.

2. A more detailed study of the New York to Chicago part of the route gives almost exactly the same wind factor as for the entire transcontinental route.

3. The altitude of flight varies with different conditions of wind and weather, but on the average may be taken as 1,500 feet above the surface. On this assumption aerological observations that have been made by means of kites and pilot balloons have been summarized, and these indicate a resultant wind very closely agreeing with the wind factor determined from the flight records themselves, the difference being less than 1 mile per hour. This agreement is close, not only in the annual means, but is almost equally good in those for the four seasons.

4. It follows from the three preceding paragraphs (*a*) that regular flights in both directions between two points, for a period of one year, furnish reliable data for the determination of the wind factor, and (*b*) that this factor can be known before any flights are made, if free-air wind data from observations with kites and balloons are available. These data make possible the computation of resultant winds, whose average effect on flights can be readily calculated from their direction and speed and from the direction of the course and the speed of the aircraft.

5. Failures to complete flights in both directions between New York and Chicago occurred on about 15 per cent of all scheduled days. A study for the year shows that the weather conditions were unfavorable somewhat more frequently than normal, and furthermore that some of the failures were not due to weather, but to other causes, such as engine trouble, etc. From these considerations it seems safe to conclude that, in an average year, with added experience and with improvements in equipment, landing fields and communication, flights could be made in both directions at least 95 per cent of the time.

6. An examination of kite and balloon records shows that winds with a west component of 36 m. p. h. or more and with an east component of 20 m. p. h. or more each occur about 5 per cent of the time. With these data and the known cruising speed of the aircraft, both normal and high, it is possible to determine time schedules which can be guaranteed on 95 per cent of the total number of days on which flights are made. Hence, including failures due to other causes, it follows that flights can be guaranteed to arrive on schedule on about 90 per cent of all days. Since the wind factor is a constant, its importance decreases markedly with increase in the normal cruising speed of the aircraft. With the cruising speed less than 80 m. p. h. no great advantage can be claimed so far as this route is concerned, over the excellent railroad service now maintained. The wind handicap can rarely, if ever, be evaded by flying around high or low pressure areas in order to gain assistance from favoring winds, since these areas usually cover a wide territory, and the gain from winds would be more than offset by the greater distance flown, not to mention the disadvantages of unfamiliarity with the route, lack of landing fields, etc.

The results of this analysis, although based entirely on day-time flights, apply equally well to night flying. There is a small diurnal variation in wind speed at the surface, with a minimum at night, but this variation ceases at a comparatively low altitude and at greater heights is opposite in phase. At the most, however, its interest in aviation is purely academic since it amounts to only a small fraction of the total wind except on comparatively quiet days. In stormy weather no variation at all is apparent.

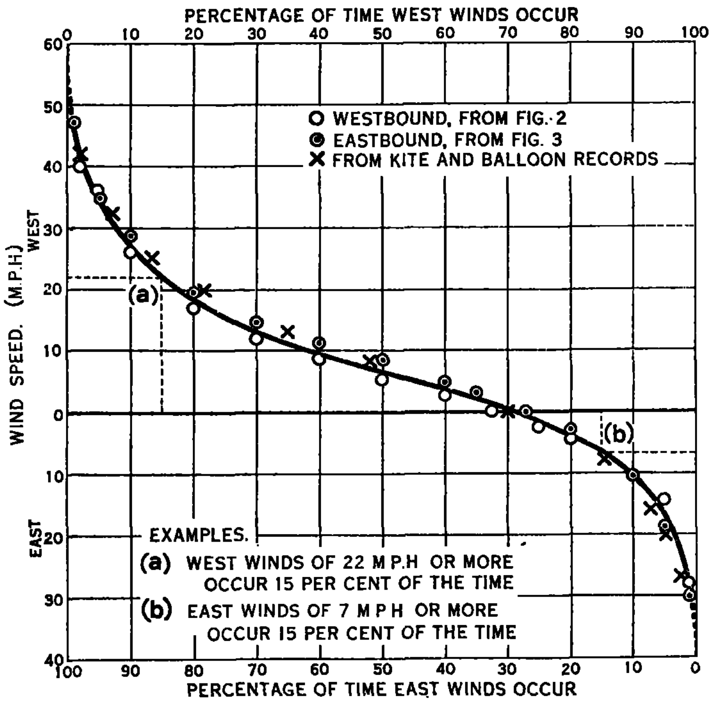

FIG. 7. Annual percentage occurrence of east and west winds of different speeds along the New York–Chicago route.

7. The results given in this paper are strictly applicable only to the Air Mail route between New York and San Francisco, and particularly to that portion of it between New York and Chicago. It has been shown that for that route the kite and balloon records make possible the determination of safe operating flight schedules. For any other route free-air observations made in that region should be used. The resultant wind for the year, and for the seasons also if desired, should be resolved into components parallel and perpendicular to the course. With these data and the cruising speed of the aircraft and with proper allowance for angle of drift the average wind factor can be easily computed. In determining flight schedules that can be guaranteed any required percentage of the time, e. g., 95 per cent, the individual wind records should be examined to find out the speed of head winds, including the equivalent component effect of cross winds, that occurs the maximum percentage of the time delayed trips are permissible, e. g., in the present case 5 per cent. Thus, if the route is from north to south and vice versa, the components into which the winds should be resolved are north and south instead of east and west as in the present paper.

8. The importance of meteorology to aviation is generally recognized. This recognition has as its primary basis the need for information as to weather conditions, current and predicted. The present study of the Air Mail records shows that the usefulness of meteorology is not thus limited, but that past data have almost equal value. In order to serve effectively both purposes there is urgent need for material extension in aerological investigations, comprising a network of stations well distributed and covering all parts of the country.

WIND DIRECTIONS AND THE ORIENTATION OF SCHOOLHOUSES.

By ROSCOE NUNN, Meteorologist.

[Weather Bureau, Nashville, Tenn., April 18, 1923.]

The purpose of this paper is to furnish information that may be useful in connection with the orientation, lighting, and ventilation of schoolhouses in the Southern States.

There is an opinion, more or less prevalent, that it is essential in the Southern States to have the windows of schoolhouses on the south side, as a rule, in order to catch the prevailing breezes in the warm season. The question has arisen whether south winds prevail to such an extent as to justify such a rule, and whether the most advantageous arrangements for lighting and sunning schoolrooms should be sacrificed to any considerable degree in order to secure openings on the south.

At the suggestion of Dr. F. B. Dresslar, of the department of health and sanitation, George Peabody College for Teachers, and special agent of the United States Bureau of Education, the writer undertook to gather statistics that would show the prevailing winds at various Weather Bureau stations for the hours 8 a. m. to 4 p. m., in the months of April, May, June, September, and October, covering the warmest part of the school year. Dr. Dresslar made an experimental investigation of the effects of various orientations of a model schoolhouse on the lighting and sunning of rooms, which showed that windows on the west or east are most advantageous.

Do southerly winds predominate to such an extent as to make it really important to have the windows of schoolrooms on the south side? Or, are the prevalence of southerly winds and the advantages to be derived from them so slight as to be negligible when weighed against the advantages of better lighting and sunning of rooms secured with west or east windows?

A condensed table of the wind-direction statistics obtained is given herewith. The table shows the prevailing direction from which the wind comes during the hours given. When we say the "prevailing" direction is, for instance, southwest, we mean that the wind came from the southwest oftener than from any other of eight directions. This does not mean that it was from the southwest most of the time; in fact, a prevailing wind, in the sense here used, might show only slightly more than one-eighth of 100 per cent of the whole, because the other seven directions might have been represented by almost one-eighth each. For example: the most frequent wind direction at Nashville, based upon records of many years, is northwest, but the general average percentage of times